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Herbicide Resistance

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HERBICIDE RESISTANCE: CROPS AND WEEDS

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Introduction

Herbicide resistance is defined as "the inherited ability of a plant to survive a dosage of a herbicide to which the wild population is sensitive". Weeds that are resistant to specific herbicides have become dominant members of field populations in many locations throughout the world. These resistant populations have caused growers considerable economic loss and long term management considerations. Plant geneticists have recently introduced crops that have been developed specifically for enhanced tolerance or resistance to herbicides that typically cause serious injury to the hybrids or varieties. These events, the development of herbicide resistant weed populations and the release of herbicide resistant crops, likely will cause considerable change in how growers manage weeds. The issues surrounding herbicide resistance will have considerable impact on agriculture in the 1990's. This paper will provide background information concerning these issues and suggest strategies that will lessen the likelihood of serious environmental and economic impact resulting from herbicide resistance.

Current World Situation for Herbicide Resistant Weeds

Weed populations that are resistant to specific herbicides have developed throughout the world. Importantly, most of the commercially available herbicide families now have weeds that are resistant to some or all of the members within the family (Table 1). Generally, herbicides that have a very specific mechanism of action are more likely to have resistant weed populations develop, however there are several examples where herbicides with less specific action have also had resistant weed populations identified.

The relative rate of weed-resistance development has increased. This is in part due to the characteristics of the new herbicide chemistry, but also as a result of the historic use of herbicides. It is important to recognize that the trait for herbicide resistance occurs naturally in a weed population. However, the probability of this trait becoming dominant within the population is dependent on the weed species and the "selection pressure" that the grower imparts on the cropping system. There are examples where resistance to a particular pesticide has never developed due to the fact that the trait for resistance does not exist within the pest population. In weeds, if the capability for the resistance trait exists, the probability of occurrence for the herbicide resistance trait has been estimated to range from 10^{-5} to 10^{-13}, depending on the specific herbicide. Given the "average" weed population in a crop field, the soil-seed reservoir, and weed-seed dormancy, the likelihood of having the resistant trait demonstrated in a weed population could be quite high.

The first agronomically important resistant weed problem in the United States was triazine resistance. This problem was first recognized in the mid-1960's in the Northwest. At that time, the problem was confined to one weed species and was economically significant in nursery crops. Since then, triazine resistance has been identified in 58 weed species worldwide, including 41 broadleaf species and 17 grass species. Importantly, many major agricultural crops now have triazine resistant weed problems. Minnesota and Wisconsin have major triazine-resistant common lambsquarters (*Chenopodium album*) and pigweed (*Amaranthus* spp.) infestations. No major problems currently exist in Iowa.

Recently, resistance to sulfonylurea herbicides has become an important concern, in part because of the rapidity in which the resistant populations developed. The resistance is characterized by an altered acetolactate synthase (ALS) enzyme in the resistant plant population. Prickly lettuce (*Lactuca serriola*) populations demonstrating resistance to sulfonylurea herbicides were first identified in Idaho, approximately three years after the first use of the herbicide. Since then, kochia (*Kochia scoparia*), Russian thistle (*Salsola kali*), common chickweed (*Stellaria media*) and perennial ryegrass (*Lolium perenne*) populations demonstrating sulfonylurea resistance have been identified in 9 states and 1 province of Canada. While these problems are primarily in cereal production and have developed quickly due to production practices specific to cereal production, the rapid and widespread development of the problems involving several diverse weed species is potentially indicative of future problems in other production systems.

Other groups of herbicides that have recently had weed resistance develop include the arylophenoxypropanoates such as quizalofop (Assure II) and fluazifop-P (Fusilade 2000), and the cyclohexanediones such as sethoxydim (Poast Plus). Weeds that have demonstrated resistance to these herbicides include wild oats (*Avena fatua*), Italian ryegrass (*Lolium multiflorum*) and goosegrass (*Eleusine indica*). Interesting in the development of resistance to these groups of herbicides is that none of these products have soil residual activity. All inhibit the same specific enzyme in grasses, Acetyl Co-A Carboxylase (ACC'ase), and resistant species may demonstrate resistance to other ACC'ase inhibitors.

Another major concern with herbicide resistance is the occurrence of cross-resistance to several herbicide families. In the aforementioned example, weeds that demonstrate resistance to arylophenoxypropanoates may also be resistant to the cyclohexanediones. Weeds that are resistant to atrazine are likely resistant to all triazine herbicides. The chlorsulfuron-resistant common chickweed demonstrated cross-resistance to several other sulfonylurea herbicides and other ALS inhibitor herbicides. Similar results are seen in the resistant kochia.

Finally, ryegrass (*Lolium rigidum*) in Australia that demonstrated resistance to paraquat has also demonstrated cross-resistance to all herbicides to which the resistant biotypes have been exposed. The herbicides include ACC'ase inhibitors, sulfonylureas, imidazolinones, and triazines. Currently, it is estimated that 600 of 40,000 growers in Australia have this resistant weed problem and it is likely that most crop acres will eventually be infested. This species of ryegrass is an obligate outcrosser. Thus, to reproduce, plants must cross with other plants; given that the resistance is a dominant trait, most ryegrass in Australia may eventually demonstrate the cross-resistance traits.

Factors Affecting Herbicide Resistance

There are several mechanisms that can confer herbicide resistance in plants. These mechanisms include: decreased herbicide uptake and/or translocation into the plant, an alteration of the herbicide target site in the plant, an overproduction of the target enzyme(s) in the resistant plant, or enhanced metabolism of the herbicide in the resistant plant. The most common mechanism demonstrated by resistant weeds is the alteration of the herbicide target site. However, the resistance mechanism that represents the greatest likelihood of herbicide cross-resistance is the enhancement of herbicide metabolism. Enhanced herbicide metabolism typically involves a group of enzymes termed mixed function oxidases (MFO's). The Australian ryegrass likely utilizes enhanced herbicide metabolism as a resistance mechanism while ALS and triazine resistant weeds utilize an altered target site.

The likelihood of herbicide resistance developing in a weed population is dependent on several factors. These factors include: high selection pressure, frequency of the resistance trait in the gene pool, specificity of the herbicide mechanism of action, plasticity of the target site, and fitness differential of the sensitive and resistant biotypes.

Selection pressure is an indication of the effectiveness of the herbicide, persistence of the herbicide, and frequency of use. A herbicide that provides consistently high levels of control will supply a high level of selection for the resistance trait. Similarly, the greater the soil life of a herbicide and the greater the frequency of use, the more likely that a resistant plant will become part of the population.

The frequency of the resistance trait in the natural gene pool is also an important consideration. The frequency of herbicide resistance has been estimated to be approximately 10^{-5} to 10^{-13}, depending on the plant species and herbicide. The resistance trait can be monogenic or polygenic; monogenic traits occur at considerably higher frequencies and likely describe most herbicide resistance. Monogene dominant traits (dominant characteristics controlled by a single gene) typically occur at frequencies of 10^{-5} to 10^{-6} while monogene recessive traits occur at frequencies of 10^{-9} to 10^{-11}. ALS resistance has been described as a monogene dominant trait and thus will occur at very high frequencies within a weed population.

A herbicide that has a very specific target site, or site of action, is at risk with regards to the likelihood of resistant weed populations developing. If a herbicide is nonspecific in the sites within the plant where the phytotoxic effects occur, there is little chance that plants can develop resistance. A plant has a greater chance of having a single modified site than simultaneous, multiple-site modifications. Triazine, sulfonylurea, and imidazolinone herbicides have a single, specific target site within plants.

Another important factor affecting the development of herbicide resistance is the plasticity of the herbicide target site. Plasticity describes the ability of the target site to be modified, such that the herbicide is no longer effective. The more simplistic that the target site is, the greater the plasticity. In many cases, modifications of target sites prove lethal to the plant and thus there is little plasticity and herbicide resistance is not likely to develop. The ALS enzyme, however, has demonstrated considerable plasticity and approximately 40 modifications (mutations) have been described that can confer resistance to ALS inhibitor herbicides such as those in the sulfonylurea and imidazolinone family.

The last factor that is important with the development of herbicide resistance is the relative fitness of the resistant biotype compared to the sensitive biotype. Generally, the modification that provides herbicide resistance does not allow the plant to grow as efficiently. For example, triazine resistant plants are approximately 1/2 to 3/4 as fit as sensitive plants. Thus, without the herbicide selection pressure, the resistant biotype will never be competitive with the sensitive biotype. However, ALS resistance apparently does not cause a major reduction in fitness when resistant plants are compared to the sensitive plants.

Herbicide Resistant Crops

Recently, biotechnology and seed companies have begun the development of crop varieties that are resistant to specific herbicides. Importantly, these crops are resistant to herbicides that would not be used on the sensitive varieties. Resistant crops are being developed for bromoxynil (Buctril), imazethapyr (Pursuit), thifensulfuron (Pinnacle), glyphosate (Roundup), gluphosinate (Ignite) and other herbicides. Herbicide resistant crops include corn, soybeans, tobacco, tomatoes, cotton, alfalfa, canola, cereals, forest trees, sunflowers, sugarbeets, oats, wheat, carrots, rice, sugarcane, petunias, and others. These research efforts have met with varied results, both in scientific considerations and with regards to environmental issues.

Imazethapyr resistant corn is currently available from ICI Seeds/Garst and it is anticipated that Pioneer will have resistant hybrids available in 1992 or 1993. While there is no registration for imazethapyr on corn, a resistant hybrid will potentially be valuable in eliminating yield losses attributable to imazethapyr carryover. These hybrids also demonstrate some cross-resistance to imazaquin (Scepter) and thus may also be useful in imazaquin carryover situations. In Canada, triazine resistant rape seed is commercially available.

Currently, no other resistant crop varieties are commercially available. However, it is anticipated that several sulfonylurea-resistant varieties of soybeans may be available to growers before 1995.

Significance of Herbicide Resistant Crops

Herbicide resistant crops represent an excellent tool for growers. Resistant crops will be important in managing specific weed problems and eliminating yield losses to carryover problems. However, environmentalists have raised several critical questions about the use of herbicide resistant crops. These questions include considerations about the ethical nature of herbicide resistant crops, whether or not herbicide resistant crops fit within the definition of sustainable agriculture, and if the use of herbicide resistant crops represent a significant environmental problem.

There is concern that the use of herbicide resistant crops will require that the grower continue to use herbicides as the major weed management strategy. In fact, it is suggested that the herbicide resistant crops will require the grower to use more herbicides. Another concern is that the resistant trait in the crops will "escape" to native plant species and thus impact the environment. It is the opinion of the author that most of the concerns expressed by these groups are not significant and will not develop into problems. However, there is one major consideration about the use of herbicide resistant crops that does represent a potential problem.

The use of herbicide resistant crops can result in growers using a single herbicide family or a single herbicide target site repeatedly. For example, if imazethapyr receives a registration for use on imazethapyr-resistant corn, Iowa growers may decide to use imazethapyr on both corn and soybean. This use practice would create intense selection pressure on the weed population. Given the high frequency that ALS resistance is estimated to exist in the natural gene pool, the repeated use of imazethapyr would likely cause the development of imazethapyr-resistant weed populations within three to five years. Thus, the use of herbicide-resistant crops represents a major potential problem by increasing the likelihood of herbicide resistant weed populations.

It should be recognized however, that currently available herbicides, if used without due consideration, can also enhance the potential for herbicide resistant weed populations. There are a number of ALS inhibitors currently available for use in corn and soybeans. These ALS inhibitors include imazethapyr, imazaquin, thifensulfuron, chlorimuron (Classic), nicosulfuron (Accent), primisulfuron (Beacon) and several other herbicides currently under development. While there may not be complete overlap of the target site when comparing these different herbicides, there may be enough commonality in the target site for many of these herbicides to provide selection pressure for a cross-resistant weed population. Thus, using different ALS-inhibitor herbicides in rotation may also select quickly for resistant weed populations.

Management Strategies to Avoid Herbicide Resistant Weeds

There are a number of management decisions that can be made that will lessen the likelihood of herbicide-resistant weed populations. It is critical, however, to evaluate each strategy on the benefits that it can provide relative to other alternative strategies. For example, moldboard plowing represents an excellent strategy to improve weed control. However, moldboard plowing soybean stubble would not warrant the relative weed control benefits given the unacceptable risks of soil erosion.

The most important strategy that can be used to minimize the development of herbicide resistant weed populations is to rotate herbicides. Do not use the same product repeatedly. However, in the case of ALS inhibitors, you must consider not only the specific herbicide, but also the herbicide family and herbicide target site.

The use of herbicide tank-mixtures has been suggested as a strategy to minimize the development of herbicide-resistant weed populations. If tank-mixtures include herbicides with different target sites, there may be some benefit with regards to herbicide resistance. However, if there is differential control of the weed in question, the use of tank-mixtures will not likely inhibit the development of resistance. For example, trifluralin (Treflan) generally will provide 80 to 85% control of pigweeds while imazethapyr will provide 90 to 95% control. The differential control of pigweed from a tank-mixture of trifluralin and imazethapyr would not likely slow the development of an imazethapyr-resistant pigweed population.

Tillage is an excellent non-selective weed management strategy. Primary tillage serves to dilute the seed population. If a resistant weed develops in a field, matures and releases seeds, a primary tillage treatment will dilute the "concentration" of the resistant seeds by placing the seeds below the zone of recruitment and mixing sensitive seeds into the seed population. Secondary tillage will provide an excellent opportunity to control weeds that escape the herbicide treatment. Thus, rotary hoe and cultivation treatments will slow the development of a herbicide resistant weed population.

Crop rotation may be another strategy that slows the development of herbicide resistant weed populations. Crops that have a different growth habit than the weed would effectively compete with the weed. In Iowa, rotations that include perennial legumes or forages could be useful in lessening the development of herbicide-resistant weed populations.

Generally, a diverse weed management program will effectively minimize the development of herbicide-resistant weed populations. A weed management strategy that takes advantage of multiple herbicide target sites, and mechanical and cultural weed control practices will be most effective in regards to herbicide resistance.

Weeds Presumed to Represent Herbicide Resistance Risks

There are several weeds found in Iowa that are presumed to be likely candidates for the development of herbicide-resistant populations, specifically ALS-herbicide resistance. These weeds include pigweeds, common lambsquarters and shattercane (*Sorghum bicolor*). The reasons that these weeds are considered as potential risks include diverse genetic configuration, apparent plasticity within the genome and high reproductive capabilities. Importantly, these weeds are found throughout Iowa. In the case of shattercane, there have been few consistent management strategies in a corn-corn rotation. Thus, ALS-inhibitor herbicides represent a valuable new management strategy and will be used frequently. Pigweeds and common lambsquarters have demonstrated resistance to other herbicides and thus are presumed to have plasticity capabilities that will allow for resistance to herbicides with other target sites. In the case of common lambsquarters, kochia, a member of the same plant family, has demonstrated ALS resistant populations.

Conclusions

Herbicide resistant weed populations have developed in many agricultural systems around the world. Importantly, while many of the herbicides to which resistant weed populations have developed are those that demonstrate long residual activity and thus considerable selection pressure, there are recent examples of weed populations that are resistant to herbicides that do not have appreciable residual activity. Current herbicide development has focused on the ALS enzyme as the target site of herbicide mechanism of action and there are numerous products now available or under development. However, ALS-inhibitor herbicides demonstrate a number of characteristics that support a concern for the rapid development of resistant weed populations. The introduction of ALS inhibitor resistance in crops will also potentially contribute to the occurrence of weed resistance. Thus it is important to recognize the factors that influence the development of herbicide resistant weed populations and utilize management strategies that reduce the potential for these populations to become established.

Table 1. Herbicide Resistance In Weeds

Herbicide Class	Specific Herbicide	Weed Species
Triazines	atrazine	*Amaranthus* spp.
Sulfonylurea	chlorsulfuron	*Kochia*
Bipyridiliums	paraquat	*Erigeron*
Dinitroanilines	trifluralin	*Eleusine*
ACC'ase Graminicides	Diclofop-methyl	*Avena* spp.
Amides	propanil	*Echinochloa*
Arsenicals	MSMA	*Xanthium*
Nitriles	bromoxynil	*Chenopodium*
Phenoxys	mecoprop	*Stellaria*
Pyridines	picloram	*Centaurea*
Ureas	IPU	*Alopecurus*
Triazole	amitrole	*Lolium*
Uracils	bromacil	*Amaranthus*
Imidazolinone	imazapyr	*Kochia*